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37/20, H05H 1/24

(52) UK CL (Edition L)

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D12B9 D12C D17D D19X D19Y D38 D8X D9A D9D  
D9L D9Y  
B6J JMG2 J501 J707  
C3L LJE L130  
H1X X5G  
U1S S1156 S1540 S1632 S1635 S1654 S1845

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(58) Field of search

UK CL (Edition K) C3L LJE LJX, H1D DGP DGQ,  
H1X X5G  
INT CL<sup>6</sup> C08J, H01J, H01T, H05H

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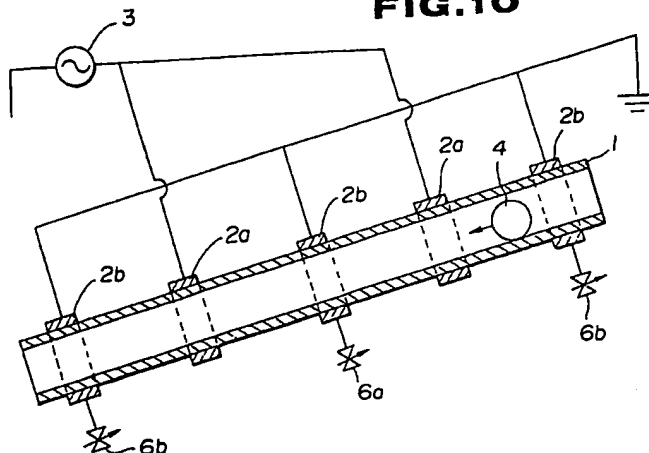
2 Cursitor Street, London, EC4A 1BQ, United  
Kingdom

(54) **Method and apparatus for surface treatment**

(57) An object (4) is subjected to a surface treatment by locating it in an atmospheric pressure plasma i.e. at 200 torr – 3 atm., while rolling or floating the object (4) in an insulating vessel (1) fed with a prescribed gas and provided on the outside thereof or on both the outside and inside thereof with electrodes (2a, 2b) which are used to form the atmospheric pressure plasma. Thus uniform surface treatment of any object in the form of lump or sphere or powder is obtained.

For example, vulcanized rubber can be surface treated with an atmospheric pressure plasma in the presence of an oxygen-containing gas and halogen containing gases to improve its adhesion properties. Numerous different electrode configurations and different gas fillings for forming the atmospheric pressure glow discharge are disclosed. As shown, the object 4 may roll down an inclined tube 1, the tube itself may be reciprocated so that the object rolls back and forth, Fig. 11 (not shown). Alternatively, the object may float up and down in a vertical tube having a hinged flap at one end, Fig. 12 (not shown). The inner electrodes may also form supports along which the objects roll, Figs 32, 33 (not shown). The objects may also be located on a moving belt, Figs 13, 14 (not shown).

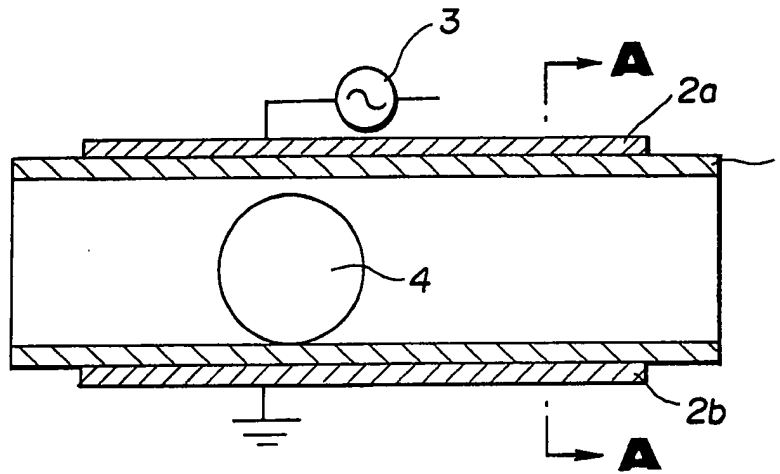
**FIG.10**



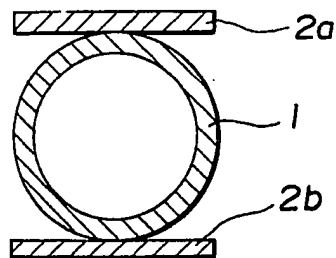
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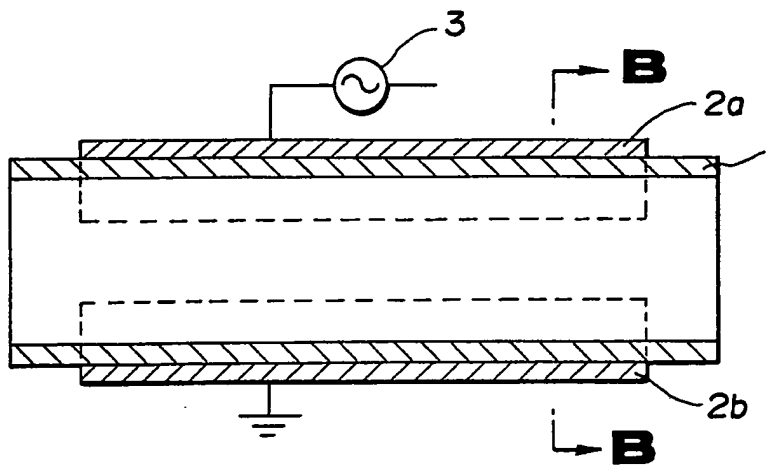
**FIG.1**



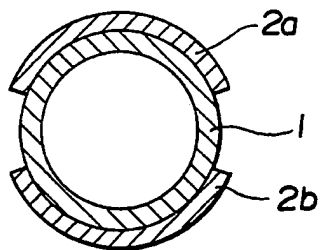
**FIG.2**



**FIG. 3**

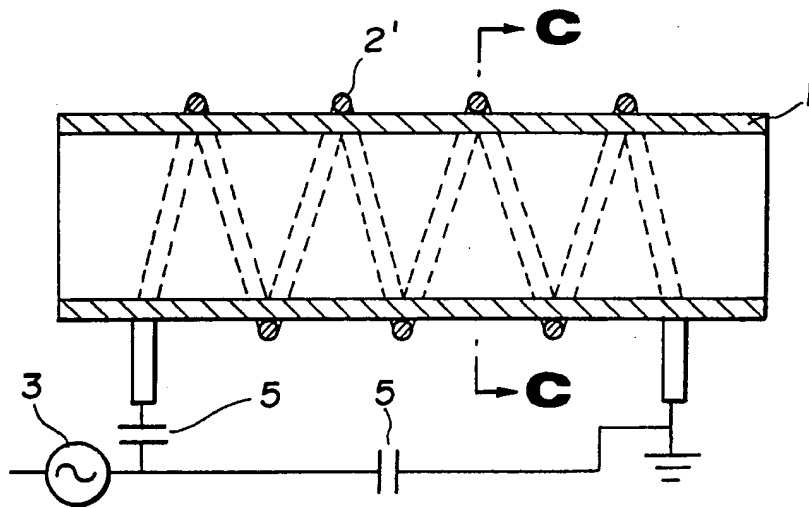


**FIG. 4**

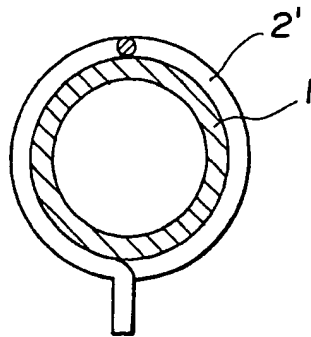


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**FIG. 5**

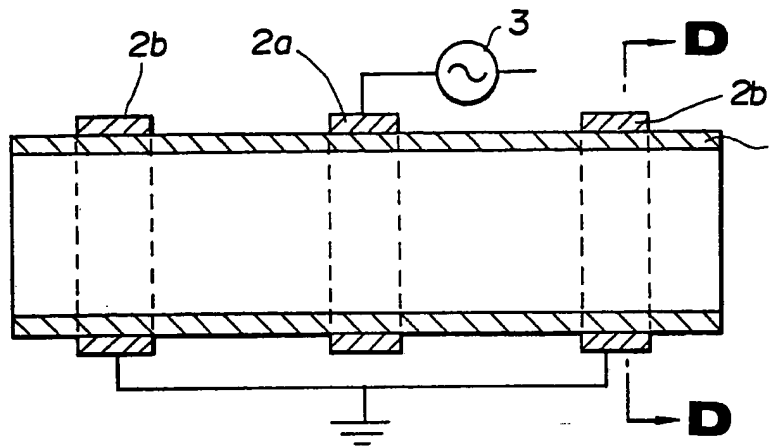


**FIG. 6**

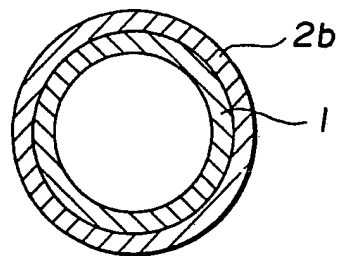


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**FIG. 7**

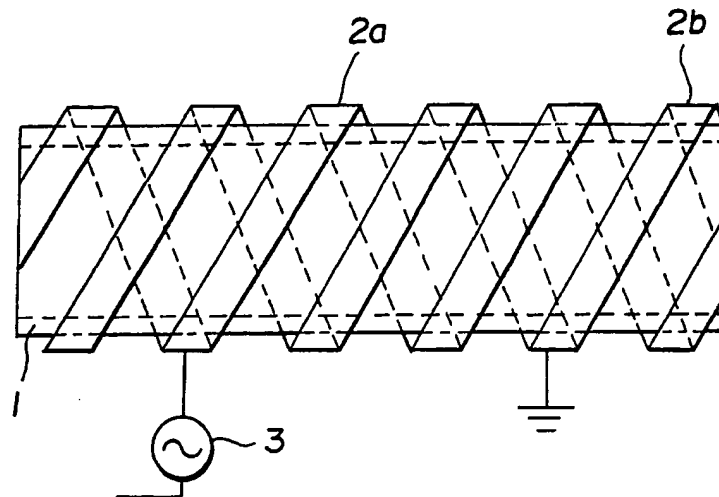


**FIG. 8**

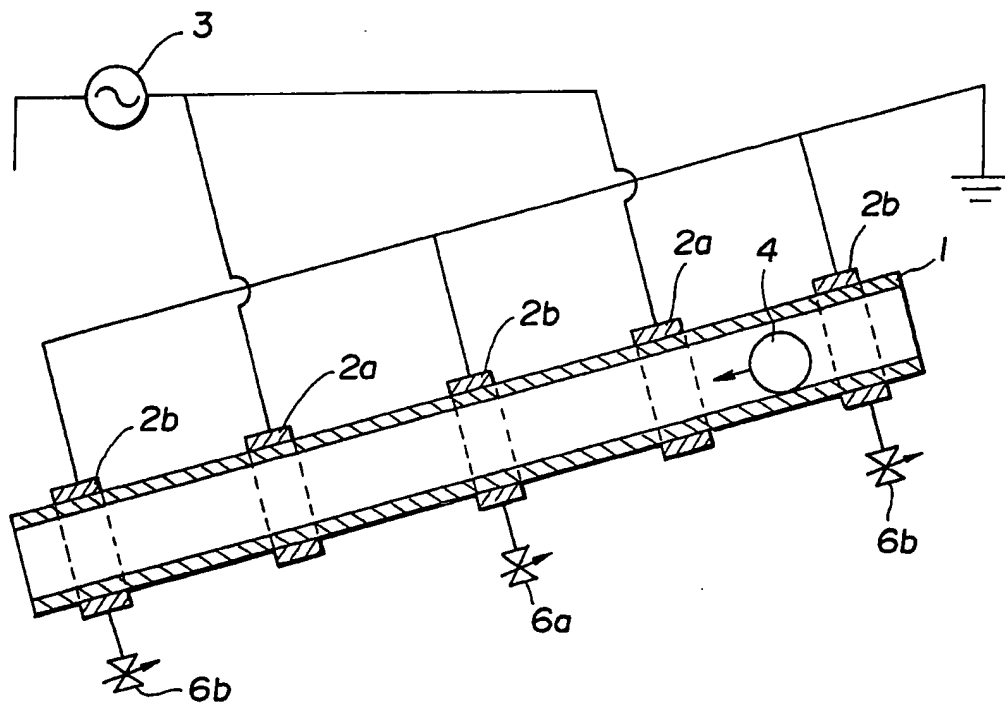


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**FIG. 9**

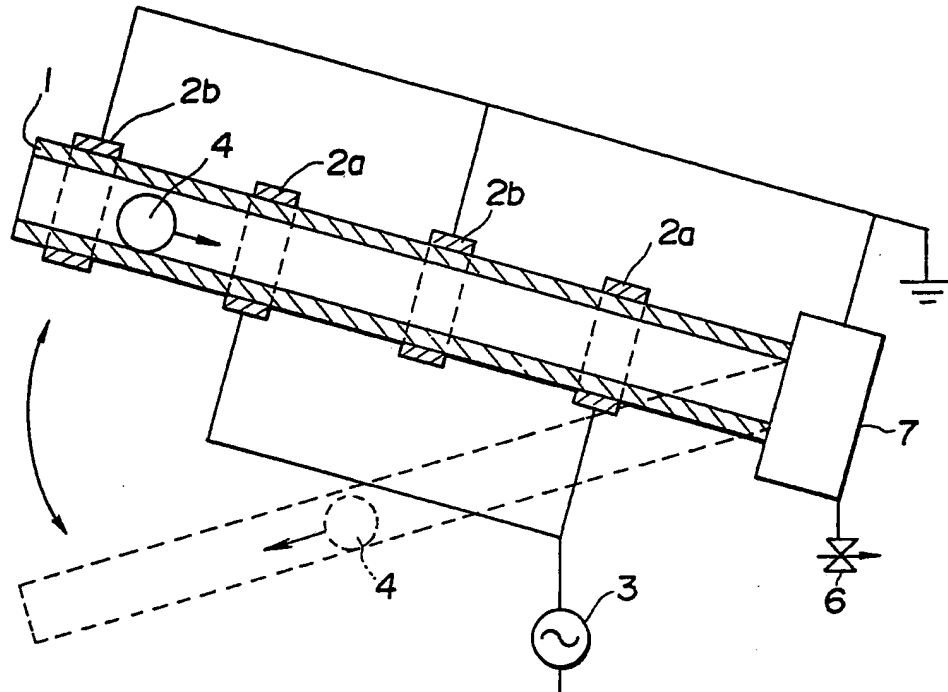


**FIG. 10**

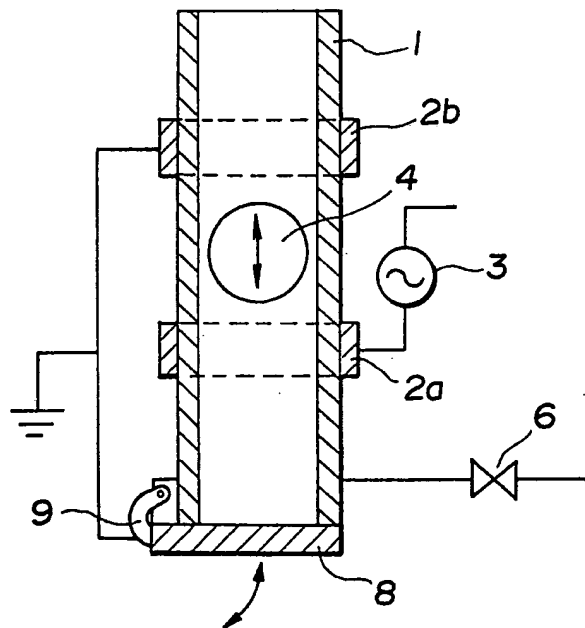


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**FIG. 11**

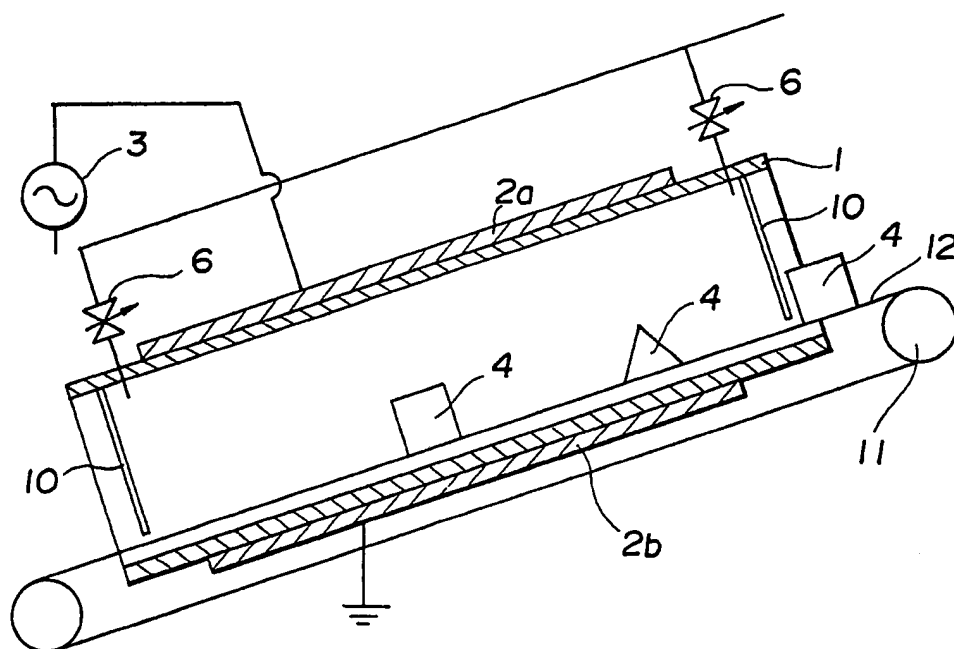


**FIG. 12**



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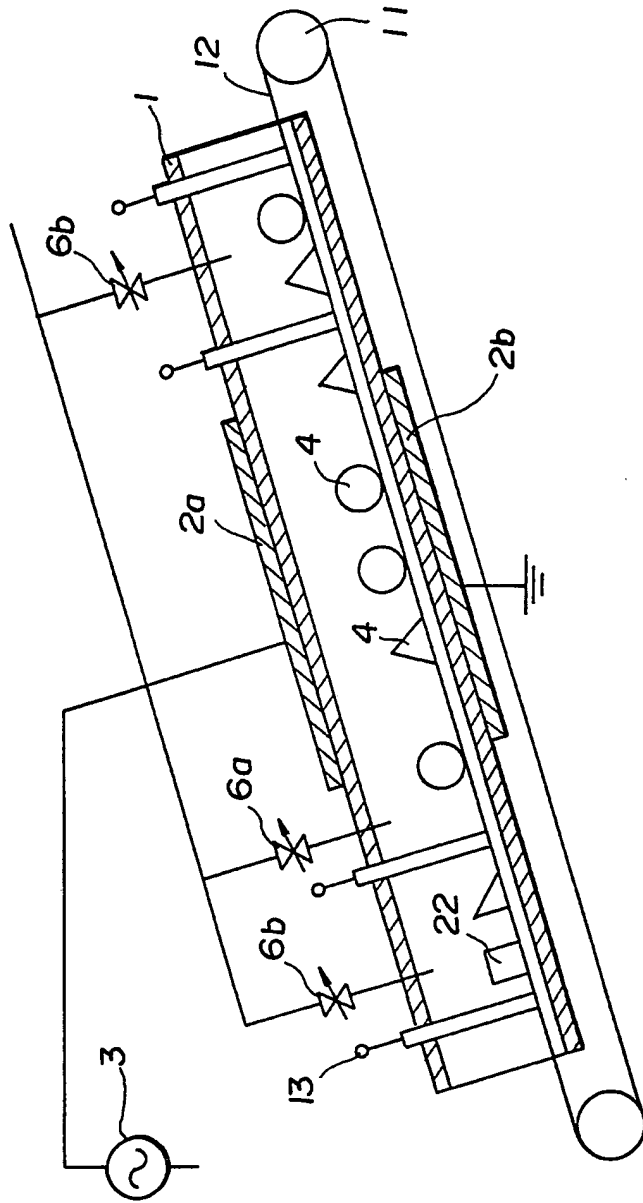
**FIG. 13**





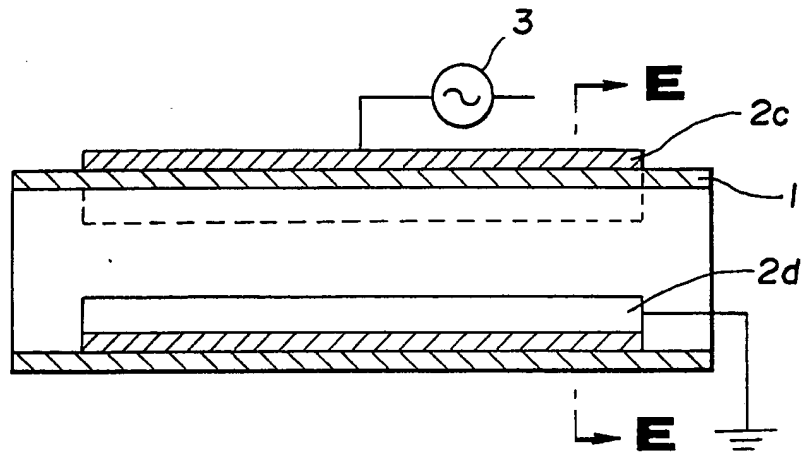
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**FIG. 14**

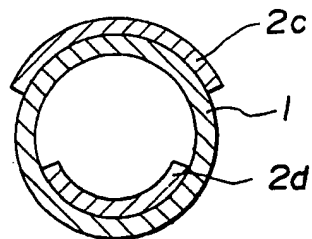


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**FIG. 15**

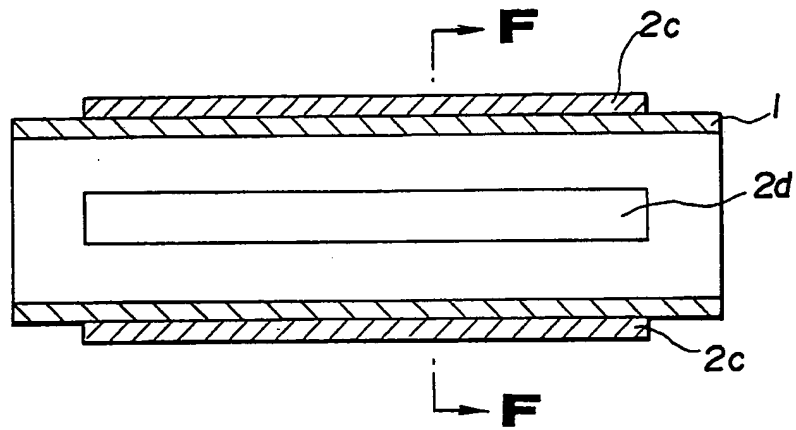


**FIG. 16**

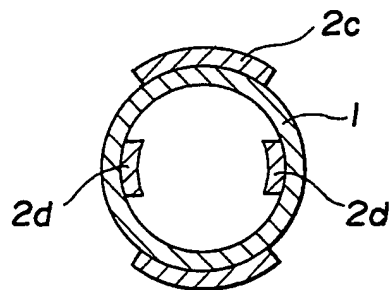


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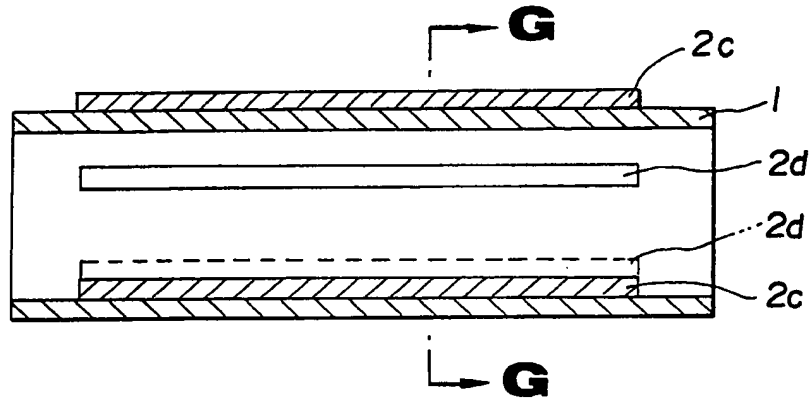
**FIG.17**



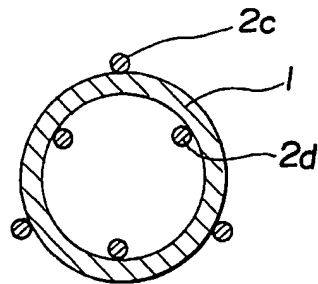
**FIG.18**



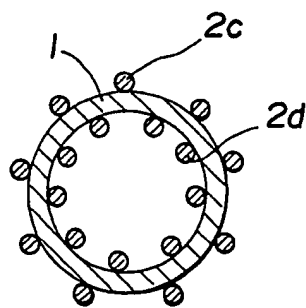
**FIG. 19**



**FIG. 20**

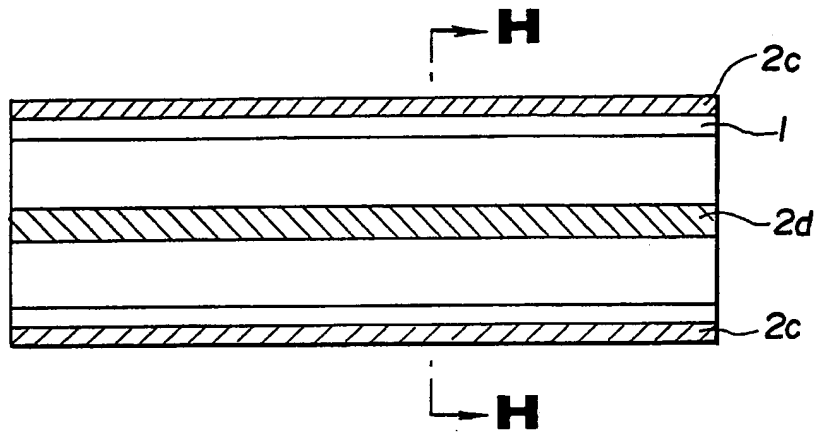


**FIG. 21**

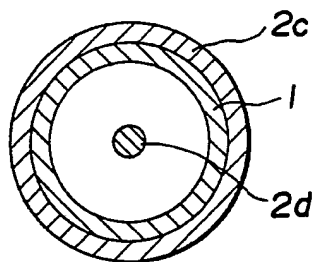


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**FIG. 22**

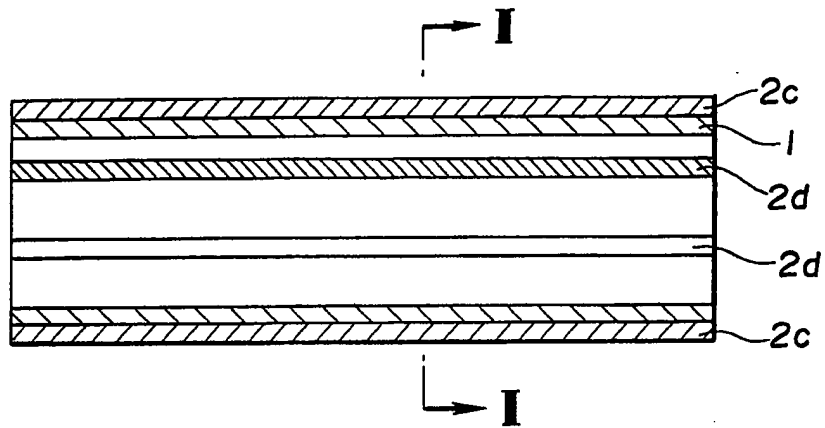


**FIG. 23**

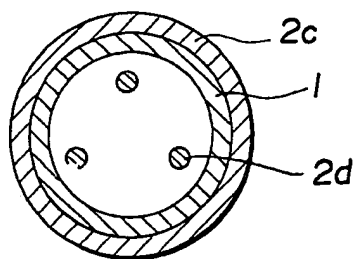


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**FIG. 24**

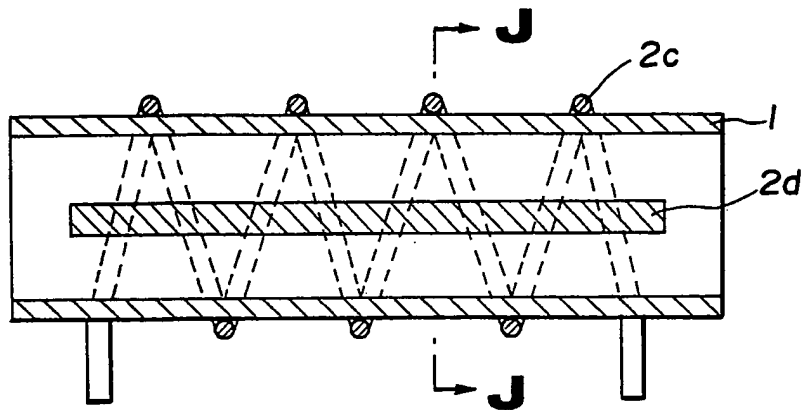


**FIG. 25**

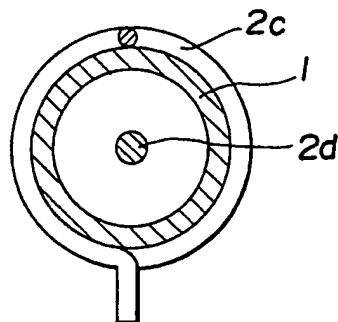


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**FIG. 26**

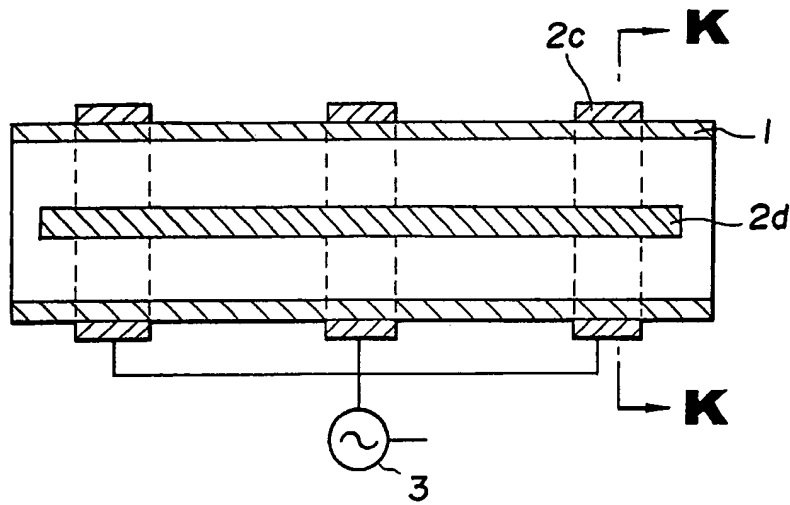


**FIG. 27**

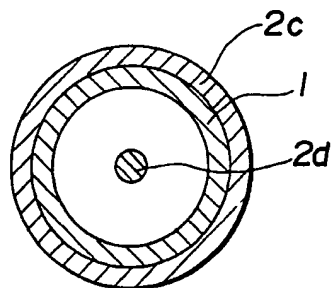


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**FIG.28**



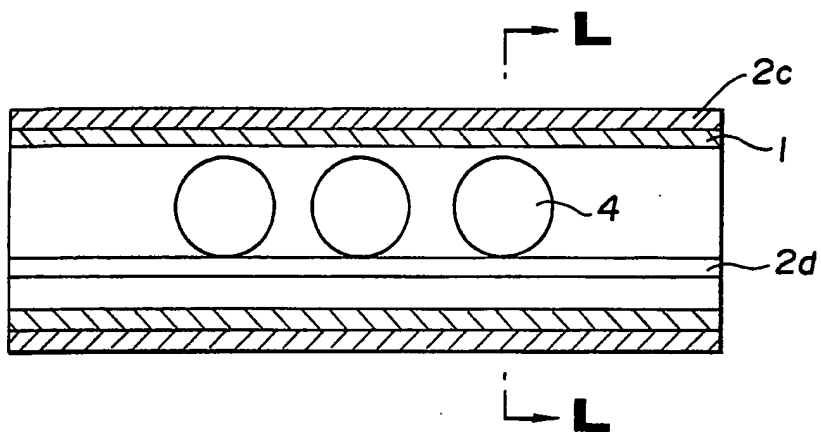
**FIG.29**



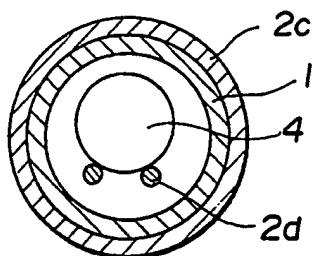


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**FIG. 30**

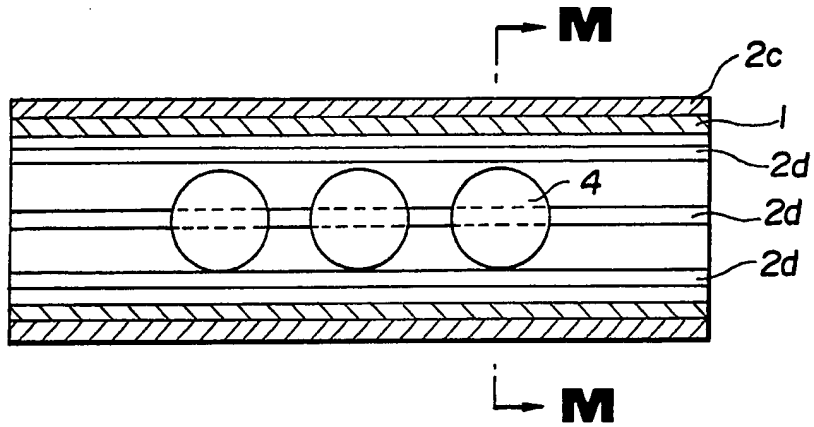


**FIG. 31**

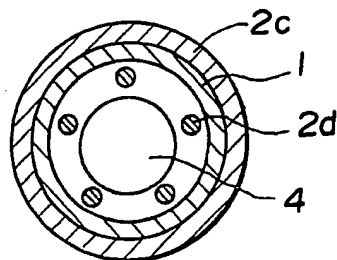


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**FIG. 32**

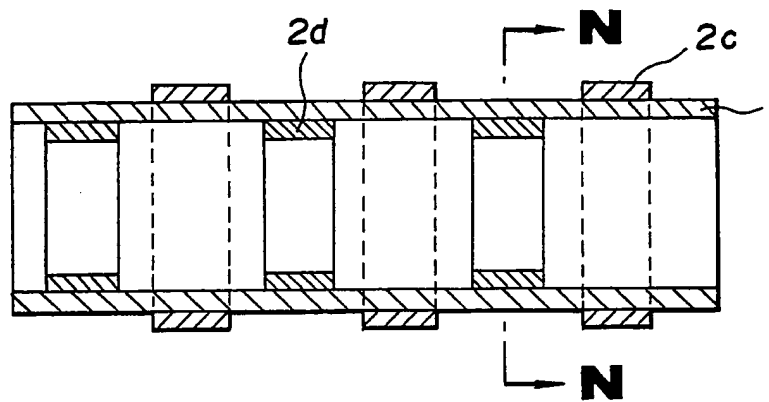


**FIG. 33**

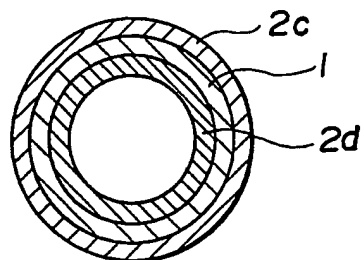


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**FIG. 34**

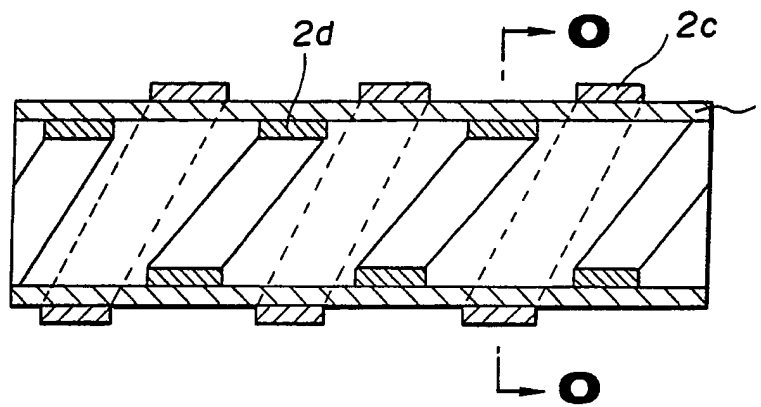


**FIG. 35**

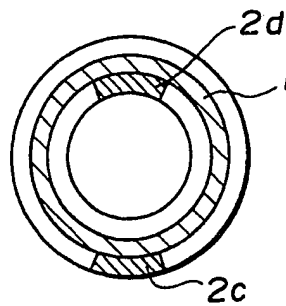


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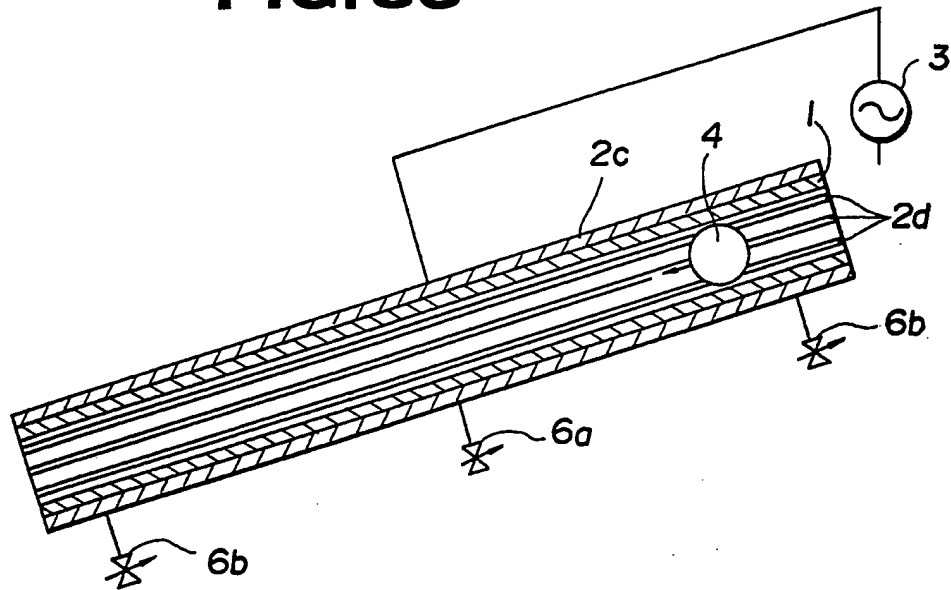
**FIG. 36**



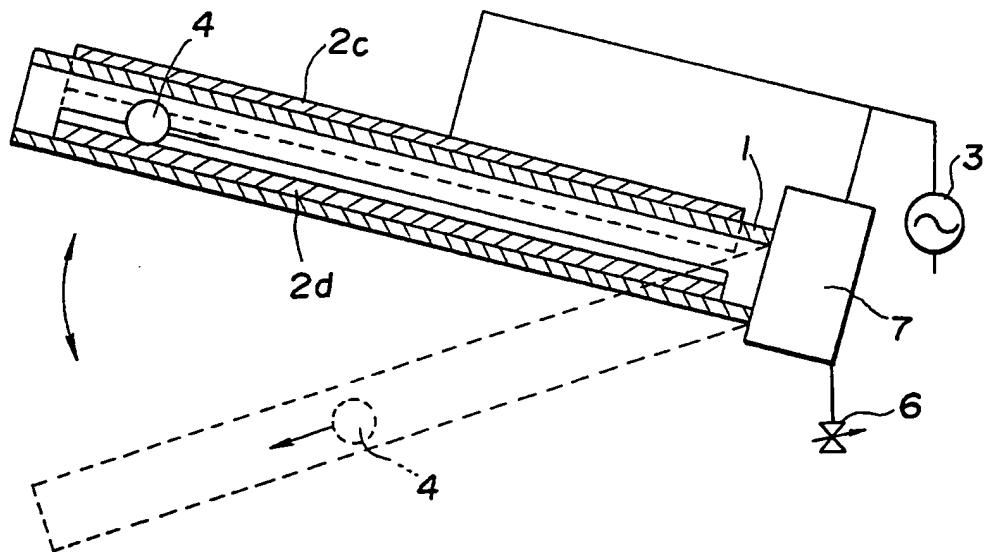
**FIG. 37**



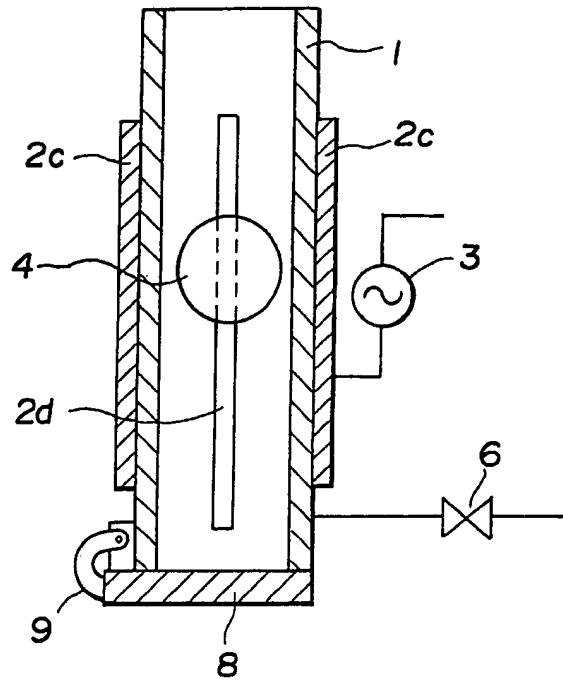
**FIG. 38**



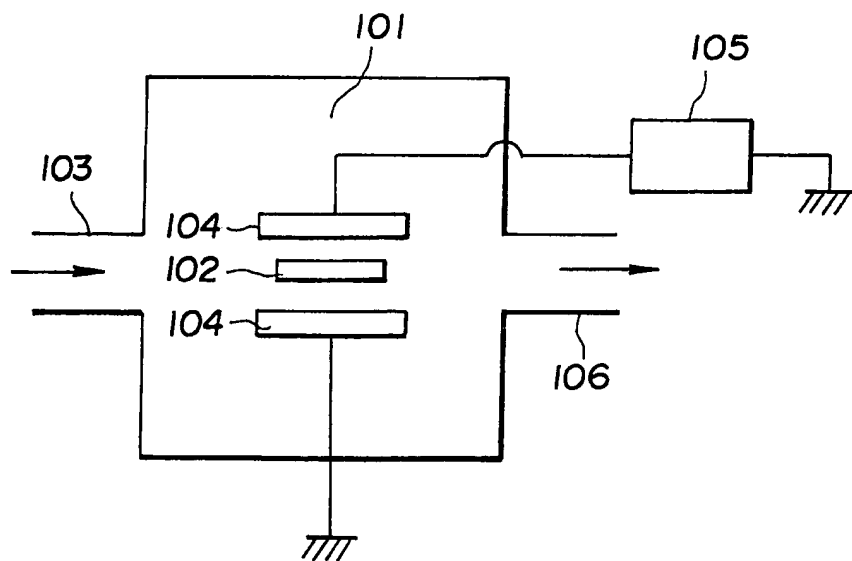
**FIG. 39**



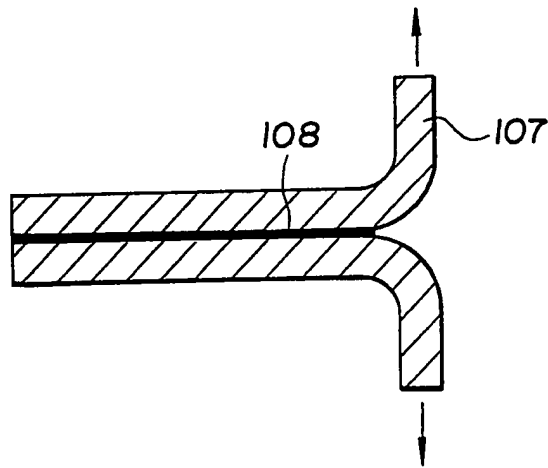
**FIG. 40**



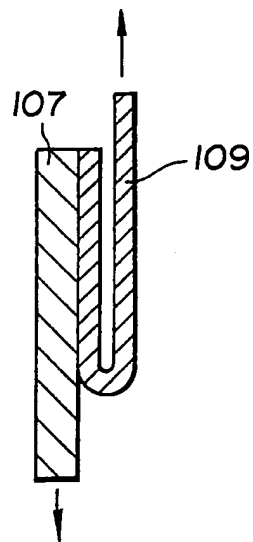
**FIG. 41**



**FIG. 42**



**FIG. 43**



## METHOD AND APPARATUS FOR SURFACE TREATMENT

5           The present invention relates to a method  
and apparatus for surface-treating any object  
in the form of lump, sphere, or powder with an  
atmospheric pressure plasma.

          The present invention also relates to a  
10 method for surface-treating vulcanized rubber  
for its joining to other materials.

          Among several known methods for surface  
treatment of objects is one which employs a  
15 low-pressure glow plasma. This method permits  
uniform surface treatment, but in its industrial  
application it needs a large-scale vacuum unit  
that produces a vacuum of 10 Torr or below. It  
also needs a high equipment cost and running  
20 cost for continuous treatment which is greatly  
affected by the life of the valve. Another  
disadvantage is the difficulty in applying to  
objects of rubber or plastics which contain a  
large amount of volatile matters. In a reduced  
25 pressure, these volatile matters evaporate and



release themselves from the surface, adversely affecting the desired object, performance, and function of plasma treatment.

There is disclosed in Japanese Patent  
5 Laid - Open Nos. 15171/1990, 48626/1990,  
241739/1991 and 236475/1991 a method for  
treating the surface of an object with a glow  
plasma obtained under atmospheric pressure.  
This method is suitable for flat objects but is  
10 not suitable for objects in the form of lump,  
sphere, or powder.

Surface treatment of vulcanized rubber has  
been a common practice where it is necessary to  
combine vulcanized rubber with other materials  
15 (or rubber, metal, or plastics) for the  
production of composite materials or it is  
necessary to perform pretreatment on vulcanized  
rubber for its finish coating. There are  
several known methods for this purpose.

20 For example, one of such known methods is  
used to impart adhesion properties to the  
surface of vulcanized rubber. It consists of  
highly oxidizing the surface of vulcanized  
rubber with a strong acid or strong oxidizing  
25 agent, thereby forming minute cracks in the

entire surface. However, it suffers from drawbacks involved in using a strong acid or oxidizing agent which needs great handling precaution and seriously damages the properties of vulcanized rubber. In addition, the surface treatment by this method does not provide a sufficient adhesion strength.

There are other methods for the surface treatment of vulcanized rubber. For example, one method consists of treating vulcanized rubber with chlorine gas, and another method consists of treating vulcanized rubber with a pseudohalide compound (See Japanese Patent Publication No. 36910/1977.) These methods are designed to attack the double bonds in rubber, thereby forming Cl-groups which promote adhesion. If these methods are applied to vulcanized rubber to be combined with other materials (such as metal and resin) for the production of anti-vibration rubber, they bring about resinification of treated surface which degrades adhesion properties and heat resistance. And they bring about the yellowing of the treated surface which are serious in the finish coating of golf balls made of balata

(transpolyisoprene). They deteriorate the appearance of golf balls. In addition, chlorine gas and pseudohalogen compound are dangerous to the environment.

5        There is another method for surface treatment. It is a low-pressure glow plasma treating method. According to this method, the surface of vulcanized rubber is treated with O<sub>2</sub> or a mixture of O<sub>2</sub> and CF<sub>4</sub> for etching oxidation  
10 and activation. This method permits uniform surface treatment, but in its industrial application it needs a large-scale vacuum unit that produces a vacuum of 10 Torr or below. It also needs a high equipment cost and running  
15 cost for continuous treatment. In addition, treatment in a reduced pressure causes the vulcanized rubber to give off oil and water which interfere with the desired performance and function.

20

It is an object of the present invention to provide novel methods and apparatus for surface treatment, suitable for objects in the form of lump, sphere, or the like, and preferably enabling a simple and uniform  
25 treatment.

In particular it would be preferable to provide a simple method for the surface treatment of vulcanized rubber which imparts good adhesion properties to the surface of vulcanized rubber to be joined to other materials for the production of good composite materials.

According to the present invention, the surface treatment of an object e.g. in the form of lump or sphere (which is not flat nor straight) can be accomplished by a first method and apparatus defined below.

A method for surface treatment which comprises subjecting an object for surface treatment to an atmospheric pressure plasma while rolling or floating said object in an insulating vessel fed with a prescribed gas and provided on the outside thereof with electrodes for voltage application and grounding, said atmospheric pressure plasma occurring upon application of a voltage to said electrodes.

An apparatus for surface treatment which comprises an insulating vessel in which an object for surface treatment is placed, electrodes for voltage application and grounding

which are arranged on the outside of the insulating vessel, an electric source to apply a voltage to said electrodes, a means to supply a prescribed gas to said insulating vessel; and a  
5 means to roll or float said object in the insulating vessel, said electrodes generating an atmospheric pressure plasma upon application of a voltage thereto and said object placed in said insulating vessel being exposed to said  
10 atmospheric pressure plasma.

The present invention employs atmospheric pressure plasma for the surface treatment of a rolling or floating object. This permits uniform surface treatment for objects of any  
15 form. The resulting treated surface permits good adhesion of coating film or adhesive over the entire surface in the coating or bonding of rubber and plastics.

The surface treatment according to the  
20 present invention is by means of an atmospheric pressure discharge which takes place in a gaseous atmosphere, usually at 80-100°C. Therefore, the surface treatment can be carried out without thermal deformation even though objects are poor  
25 in heat resistance. In addition, the surface

treatment under the atmospheric pressure can be performed on rubber and plastics without evaporation of volatile matters contained therein.

5           Another advantage of the surface treatment with the plasma is accurate temperature control in the case where objects are exposed to a high temperature. This is because the temperature of objects is affected only a little by the plasma.

10           According to the present invention, the surface treatment of an object e.g. in the form of lump or sphere (which is not flat nor straight) can also be accomplished by a second method and apparatus defined below.

15           A method for surface treatment which comprises subjecting an object for surface treatment to an atmospheric pressure plasma while rolling or floating said object in an insulating vessel fed with a prescribed gas and  
20 provided on the outside and inside thereof with electrodes for voltage application, said atmospheric pressure plasma occurring upon application of a voltage to said electrodes.

          An apparatus for surface treatment which  
25 comprises an insulating vessel in which an

object for surface treatment is placed, two  
electrodes which are arranged on the outside and  
inside of the insulating vessel, an electric  
source to apply a voltage to said electrodes, a  
5 means to supply a prescribed gas to said  
insulating vessel, and a means to roll or float  
said object in the insulating vessel, said  
electrodes generating an atmospheric pressure  
plasma upon application of a voltage thereto and  
10 said object placed in said insulating vessel  
being exposed to said atmospheric pressure  
plasma.

The second method and apparatus offer not  
only the same advantages as the first ones but  
15 also the following additional advantage. The  
electrodes arranged on both the outside and  
inside of the insulating vessel permit discharge  
to start at a very low voltage (as demonstrated  
in Example 6 given later).

20

Atmospheric pressure plasma treatment permits  
the surface of vulcanized rubber to be treated  
with a gas containing oxygen and halogen. Such  
surface treatment needs no solvent and hence  
25 presents no possibility of environmental

pollution. The surface treatment imparts much better adhesion properties to the surface of vulcanized rubber than in the case of surface treatment by the conventional method which  
5 employs a low-pressure glow plasma. Moreover, the surface treatment affects only a very thin surface layer, without any damage to the vulcanized rubber itself.

#### 10 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a partial longitudinal sectional view showing a surface-treating apparatus embodying the present invention.

Fig. 2 is a sectional view taken along the  
15 line A-A in Fig. 1.

Fig. 3 is a partial longitudinal sectional view showing another surface-treating apparatus;

Fig. 4 is a sectional view taken along the  
20 line B-B in Fig. 3.

Fig. 5 is a partial longitudinal sectional view showing another surface-treating apparatus;

Fig. 6 is a sectional view taken along the  
25 line C-C in Fig. 5.



Fig. 7 is a partial longitudinal sectional view showing another surface-treating apparatus;

Fig. 8 is a sectional view taken along the  
5 line D-D in Fig. 7.

Fig. 9 is a partial longitudinal sectional view showing another surface-treating apparatus;

Fig. 10 is a partial longitudinal  
10 sectional view showing another surface-treating apparatus;

Fig. 11 is a partial longitudinal sectional view showing another surface-treating apparatus;

15 Fig. 12 is a partial longitudinal sectional view showing another surface-treating apparatus;

Fig. 13 is a partial longitudinal sectional view showing another surface-treating  
20 apparatus;

Fig. 14 is a partial longitudinal sectional view showing another surface-treating apparatus;

Fig. 15 is a partial longitudinal  
25 sectional view showing another surface-treating

apparatus;

Fig. 16 is a sectional view taken along the line E-E in Fig. 15.

Fig. 17 is a partial longitudinal sectional view showing another surface-treating apparatus;

Fig. 18 is a sectional view taken along the line F-F in Fig. 17.

Fig. 19 is a sectional view showing another surface-treating apparatus;

Fig. 20 is a sectional view taken along the line G-G in Fig. 19.

Fig. 21 is a partial longitudinal sectional view showing a surface-treating apparatus;

Fig. 22 is a partial longitudinal sectional view showing a surface-treating apparatus;

Fig. 23 is a sectional view taken along the line H-H in Fig. 22.

Fig. 24 is a partial longitudinal sectional view showing another surface-treating apparatus;

Fig. 25 is a sectional view taken along

the line I-I in Fig. 24.

Fig. 26 is a partial longitudinal sectional view showing another surface - treating apparatus;

5        Fig. 27 is a sectional view taken along the line J-J in Fig. 26.

Fig. 28 is a partial longitudinal sectional view showing another surface - treating apparatus;

10       Fig. 29 is a sectional view taken along the line K-K in Fig. 28.

Fig. 30 is a partial longitudinal sectional view showing another surface - treating apparatus;

15       Fig. 31 is a sectional view taken along the line L-L in Fig. 30.

Fig. 32 is a partial longitudinal sectional view showing another surface - treating apparatus;

20       Fig. 33 is a sectional view taken along the line M-M in Fig. 32.

Fig. 34 is a partial longitudinal sectional view showing another surface - treating apparatus;

25       Fig. 35 is a sectional view taken along

the line N-N in Fig. 34.

Fig. 36 is a partial longitudinal sectional view showing another surface-treating apparatus;

5        Fig. 37 is a sectional view taken along the line O-O in Fig. 36.

Fig. 38 is a partial longitudinal sectional view showing another surface-treating apparatus;

10       Fig. 39 is a partial longitudinal sectional view showing another surface-treating apparatus;

Fig. 40 is a partial longitudinal sectional view showing another surface-treating  
15       apparatus;

Fig. 41 is a schematic diagram showing an atmospheric pressure plasma discharge unit;

Fig. 42 is a diagram illustrating the T-peel test used in Examples and Comparative  
20       Examples.

Fig. 43 is a diagram illustrating the 180° peel test used in Examples and Comparative  
Examples.

25

The present invention is embodied in a  
5 first method for surface treatment which  
comprises subjecting an object for surface  
treatment to an atmospheric pressure plasma in  
an insulating vessel fed with a prescribed gas  
and provided on the outside thereof with  
10 electrodes for voltage application and ground-  
ing, said atmospheric pressure plasma occurring  
upon application of a voltage to said  
electrodes.

The present invention is also embodied in  
15 a second method for surface treatment which  
comprises subjecting an object for surface  
treatment to an atmospheric pressure plasma in  
an insulating vessel fed with a prescribed gas  
and provided on the outside and inside thereof  
20 with electrodes for voltage application, said  
atmospheric pressure plasma occurring upon  
application of a voltage to said electrodes.

The object for surface treatment is not  
specifically restricted in shape so long as it  
25 is capable of rolling or floating in the

insulating vessel. It may be in the form of triangular lump, rectangular lump, polygonal lump (octahedron, dodecahedron, icosahedron, etc.), sphere, ellipsoid, or powder. In<sup>-</sup>  
5 addition, it is not specifically restricted in material. It may be made from metal, metal compound, rubber, plastics, or ceramics.

The insulating vessel used in the present invention is not specifically restricted in  
10 material, size, and shape so long as it is capable of generating a plasma and rolling or floating an object therein for surface treatment. It may be made from glass, plastics or ceramics. For the uniform surface treatment of  
15 a spherical object, it should preferably be in the form of a cylinder large enough for the object to roll therein. The wall thickness of the insulating vessel should be smaller than 10 mm, preferably smaller than 3 mm.

20 The electrode for voltage application is not specifically restricted in size and shape so long as it is capable of generating a plasma.

Atmospheric pressure plasma for surface  
25 treatment is obtained stably by the aid of a

specific gas which facilitates the generation of atmospheric pressure discharge. Examples of the gas include inert gas (such as helium, argon, and neon), non-polymerizable gas (such as  
5 nitrogen and oxygen), and organic gas. They may be used alone or in combination with one another. Of these example, helium and neon are desirable. In the case where the object of surface treatment is to improve the adhesion  
10 properties of an object, the above-mentioned list may be expanded to include nitrogen gas, oxygen gas, halogen gas and halogen compound (such as chlorine, bromine, hydrogen chloride, hydrogen bromide, bromine cyanide, tin bromide,  
15 and carbon tetrafluoride), sulfur, sulfur trioxide, hydrogen sulfide, ammonia, carbon monoxide, carbon dioxide, and hydrogen. For the stable generation of atmospheric pressure plasma, these gases should be diluted with an  
20 inert gas which facilitates the generation of atmospheric pressure discharge.

It is not necessarily essential that these gases be gaseous at normal temperature. They should be fed in a proper way which is selected  
25 according to their state (solid, liquid, or gas)

at normal temperature and the temperature in the discharge region. Those which are gaseous at normal temperature or at a temperature in the discharge region may be introduced as such into the insulating vessel. Those which are liquid having a comparatively high vapor pressure may be introduced in the form of vapor or after bubbling with an inert gas. Those which are liquid having a comparatively low vapor pressure may be introduced after heating for evaporation or increasing the vapor pressure.

The pressure for generating a plasma is preferably in the range of about 200 Torr to about 3 atm, more desirably about 1 atm.

15

A variety of methods may be used for forming a plasma in the insulating vessel. In a first method, an AC voltage should be applied to the electrodes arranged on the outside of the insulating

20

vessel. In a second method, either direct current and alternating current may be used for voltage application, with the latter being industrially desirable. The frequency should be higher than hundreds of hertz as in the ordinary AC discharge. The application of a voltage will

25



be explained below with reference to one example illustrated in Figs. 15 and 16. There are shown a cylindrical insulating vessel 1, an electrode 2c arranged on the outside thereof, and an

5 electrode 2d arranged on the inside thereof.

Voltage may be applied to either the outer electrode 2c or inner electrode 2d. That is, an AC voltage may be applied to the outer electrode 2c from an AC power source 3, as shown in Fig.

10 15. Alternatively, an AC voltage may be applied to the inner electrode 2d. The opposite electrode may or may not be grounded. In either case, it is possible to generate stable discharge at a low voltage.

15 What is important in the surface treatment with an atmospheric pressure plasma according to the present invention is to roll or float an object for surface treatment. The rolling of an object may be accomplished by inclining or  
20 swinging the cylindrical insulating vessel. The floating of an object may be accomplished by injecting a treating gas into the insulating vessel.

The above method can generate an  
25 atmospheric pressure glow plasma which gives the

best effect on surface treatment of a golf ball.

However, in the present invention, an atmospheric pressure plasma may be generated by the other discharge methods including corona  
5 discharge, filament discharge and the like.

A preferred example of the apparatus used for surface treatment according to the first method of the present invention will be explained with reference to the accompanying  
10 drawings. Figs. 1 and 2 show an apparatus for the surface treatment of an spherical object 4 with a plasma. It is made up of an insulating vessel 1 and flat parallel electrodes 2a (for voltage application) and 2b (for grounding)  
15 across which a voltage is applied by an AC power source 3. Figs. 3 and 4 show an apparatus which is made up of an insulating vessel 1 and arched electrodes 2a and 2b arranged opposite to each other. Figs. 5 and 6 show an apparatus which is  
20 made up of an insulating vessel 1 and an elongate electrode 2' spirally wound around the insulating vessel 1. A voltage is applied to one end of the electrode 2' through a capacitor 5, with the other end grounded. Figs. 7 and 8  
25 show an apparatus which is made up of an

insulating vessel 1 and annular electrodes 2a  
(for voltage application) and 2b (for grounding)  
which are arranged alternately at certain  
intervals. Fig. 9 shows an apparatus which is  
5 made up of elongate electrodes 2a (for voltage  
application) and 2b (for grounding) which are  
spirally wound around the insulating vessel at  
certain intervals.

Those apparatuses shown above permit a  
10 spherical object 4 to roll in the insulating  
vessel 1, as shown in Figs. 10 and 11. If the  
inside diameter of the insulating vessel 1 is  
close to the outside diameter of the spherical  
object 4, they permit the spherical object to  
15 roll smoothly without jams and minimize the  
diffusion of the treating gas (such as helium)  
into the atmosphere.

The apparatuses shown in Fig. 1-9 should  
preferably be arranged as shown in Figs. 10-14  
20 for spherical objects which are rolled during  
surface treatment. Fig. 10 shows an apparatus  
which is provided with the electrodes shown in  
Figs. 7 and 8. It is designed such that the  
vessel 1 is inclined so that a spherical object  
25 4 rolls down during surface treatment with an

atmospheric pressure plasma. The insulating vessel 1 is fed with a prescribed gas from a gas supply means (not shown) through a main gas inlet 6a. There are two auxiliary gas inlets 6b and 6b at the ends of the insulating vessel 1. This arrangement of gas inlets minimizes the diffusion of the gas into the atmosphere.

Fig. 11 shows an apparatus provided with the electrodes as shown in Figs. 7 and 8. This apparatus is designed such that one end of the insulating vessel 1 is fixed to a swinging mechanism 7 which swings so as to move the other end of the insulating vessel 1 up and down for the reciprocal movement of a spherical object in the insulating vessel during surface treatment. The treating gas is introduced into the insulating vessel 1 through a gas inlet 6 attached to the swinging mechanism 7. This arrangement minimizes the diffusion of the treating gas into the atmosphere.

Furthermore, Fig. 12 shows an apparatus provided with the electrodes as shown in Figs. 7 and 8. This apparatus is designed such that the insulating vessel 1 is held vertical, with the upper end thereof open and the lower end thereof

provided with a hinged door 8. The hinged door 8 is opened to place a spherical object 4 in the insulating vessel 1. This treating gas is introduced into the insulating vessel 1 so as to float and roll the spherical object 4 for surface treatment. It is important that the gap between the insulating vessel 1 and the spherical object 4 be properly controlled.

In the embodiments shown in Figs. 10-12 above, the apparatuses employ the electrodes shown in Figs. 7 and 8; however, they are illustrative only and it is possible to use other electrodes.

Fig. 10 shows an apparatus which is designed such that the surface treatment of an object with an atmospheric pressure plasma is carried out while the object is rolling in the insulating vessel. The apparatus shown in Fig. 10 may be modified such that the movement of an object may be accomplished by means of a belt conveyor as shown in Fig. 13.

The embodiment shown in Fig. 13 is provided with the electrodes shown in Figs. 1 and 2. The square cylindrical insulating vessel 1 is provided with gas inlets 6a and 6a and

curtains 10 and 10 at the ends of the insulating vessel 1. The curtains prevent the treating gas from diffusing into the atmosphere. The objects 4 and 4 for surface treatment are placed on a  
5 belt 12 and moved at a prescribed rate by a drive mechanism 11.

The embodiment shown in Fig. 14 is similar to that shown in Fig. 13. It is provided with gates 13 which divide the insulating vessel 1  
10 into three compartments. The central compartment is provided with a main gas inlet 6a and the other compartments are provided with auxiliary gas inlets 6a and 6a.

A preferred example of the apparatus used  
15 for surface treatment according to the second method of the present invention will be explained with reference to Figs. 15 - 40.

Figs. 15 and 16 show an apparatus made up of a cylindrical insulating vessel 1 and an  
20 arched outer electrode 2c and an arched inner electrode 2d which are opposite to each other. A voltage is applied to the outer electrode 2c from an AC power source 3. Figs. 17 and 18 show an apparatus made up of an insulating vessel 1,  
25 two arched outer electrodes 2c and 2c opposite

to each other, and two inner arched electrodes  
2d and 2d opposite to each other, with the outer  
and inner electrodes shifted  $90^\circ$  with respect to  
each other. Figs. 19 and 20 show an apparatus  
5 made up of an insulating vessel 1, elongate  
outer electrodes 2c arranged at certain  
intervals, and elongate inner electrodes 2d  
arranged at certain intervals. Fig. 21 shows an  
apparatus provided with nine outer electrodes 2c  
10 and nine inner electrodes 2d. Figs. 22 and 23  
show an apparatus made up of an insulating  
vessel 1, a cylindrical outer electrode 2c  
surrounding the insulating vessel 1, and an  
elongate inner electrode 2d arranged in the  
15 insulating vessel 1. Figs. 24 and 25 show an  
apparatus made up of an insulating vessel 1, a  
cylindrical outer electrode 2c surrounding the  
insulating vessel, and three elongate inner  
electrodes 2d arranged at certain intervals in  
20 the insulating vessel 1. Figs. 26 and 27 show  
an apparatus made up of an insulating vessel 1,  
an elongate outer electrode 2c spirally wound  
around the insulating vessel 1 at certain  
intervals, and an elongate inner electrode 2d  
25 arranged in the insulating vessel 1. Figs. 28

and 29 show an apparatus made up of an insulating vessel 1, several ring-like outer electrodes 2c arranged at certain intervals, and an elongate inner electrode 2d arranged in the insulating vessel 1. Figs. 30 and 31 show an apparatus made up of an insulating vessel 1, a cylindrical outer electrode 2c surrounding the insulating vessel 1, and two elongate electrodes 2d and 2d arranged certain distance apart in the insulating vessel 1. The inner electrodes 2d and 2d function as a guide for the objects 4 to roll smoothly without jams. The inner electrodes 2d and 2d should preferably be positioned such that the objects 4 placed thereon are as close to the insulating vessel 1 as possible. Figs. 32 and 33 show an apparatus (similar to that shown in Figs. 30 and 31) which is designed such that five elongate inner electrodes 2d are arranged in a circle at certain intervals. An object 4 is placed in the space formed by these inner electrodes 2d.

Those embodiments shown in Figs. 15 - 33 are designed such that a voltage may be applied to either the outer electrode or the inner electrode. Those embodiments shown in Figs.



34 - 37 are designed such that a voltage is applied to the outer electrode. Figs. 34 and 35 show an apparatus made up of an insulating vessel 1 and ring-like outer electrodes 2c and ring-like inner electrodes 2d arranged at certain intervals. The inner electrodes 2d are left ungrounded. Figs. 36 and 37 show an apparatus made up of an insulating vessel 1 and oblique ring-like outer electrodes 2c and oblique ring-like inner electrodes 2d arranged at certain intervals. As in the case of the apparatus shown in Figs. 34 and 35, the inner electrodes 2d are left ungrounded.

To facilitate the rolling of objects for surface treatment in the apparatuses shown in Figs. 15 - 37, it is desirable to use an apparatus as shown in Figs. 38 and 39. The apparatus shown in Fig. 38 is provided with the electrodes as shown in Figs. 32 and 33. When in use, the apparatus permits an object 4 to roll through the insulating vessel 1 fixed inclined and undergo surface treatment by the atmospheric pressure plasma. The insulating vessel 1 is fed with a prescribed gas through a main gas inlet 6a at the center of the insulating vessel 1 from

a gas supply means (not shown). There are two auxiliary gas inlets 6b and 6b at the ends of the insulating vessel 1. This arrangement of gas inlets minimizes the diffusion of the gas into the atmosphere.

Fig. 39 shows an apparatus provided with the electrodes as shown in Figs. 15 and 16. This apparatus is designed such that one end of the insulating vessel 1 is fixed to a swinging mechanism 7 which swings so as to move the outer end of the insulating vessel 1 up and down for the reciprocal movement of an object 4. The treating gas is introduced into the insulating vessel 1 through a gas inlet 6 attached to the swinging mechanism 7. This arrangement minimizes the diffusion of the treating gas into the atmosphere.

Incidentally, although the apparatuses shown in Figs. 38 and 39 are provided with the electrodes shown in Figs. 32-33 and Figs. 15-16, it is also possible to use other electrodes. In the case of an apparatus as shown in Fig. 38, it is possible to perform surface treatment while moving an object by means of a belt conveyor.

Furthermore, Fig. 40 shows an apparatus provided with the electrodes as shown in Figs. 17 and 18. This apparatus is designed such that the insulating vessel 1 is held vertical, with the upper end thereof open and the lower end thereof provided with a hinged door 8. The hinged door 8 is opened to place an object 4 in the insulating vessel 1. The treating gas is introduced into the insulating vessel 1 through a gas inlet 6 at the bottom of the insulating vessel 1 so as to float and roll the object 4 for surface treatment. It is important that the gap between the insulating vessel 1 and the object 4 be properly controlled.

According to the method described above, it is possible to carry out the surface treatment of objects in the form of lump or sphere uniformly and certainly in a simple manner. The surface treatment is by means of the atmospheric pressure plasma which does not need the treating apparatus to be evacuated. The surface treatment at atmospheric pressure requires only a simple treating apparatus and can be applied to any objects without evaporation of volatile matters contained

therein.

The present invention also provides a method for surface treatment of vulcanized rubber. This method consists of treating the surface of vulcanized rubber with an atmospheric pressure plasma in the presence of an oxygen-containing gas and halogen-containing gases.

This method can be applied to any vulcanized rubber, which includes, for example, NR (natural rubber), SBR (styrene-butadiene rubber), IR (isoprene rubber), NBR (acrylonitrile butadiene rubber), EPM (ethylene propylene rubber), EPDM (ethylene propylene diene rubber), BR (butadiene rubber), IIR (butyl rubber), and CR (chloroprene rubber). The vulcanized rubber may be in any form, including plate, sheet, sphere, cylinder, column, and lump.

The surface treatment employs an oxygen-containing gas, which includes, for example, oxygen, water vapor, carbon dioxide, alcohols, ketones, and ethers. Of these gases, oxygen is preferable.

The surface treatment employs a halogen-containing

gas, which includes, for example, simple substance gas (such as  $F_2$ ,  $Cl_2$ ,  $Br_2$ , and  $I_2$ ), hydrogen halide (such as  $HF$ ,  $HCl$ ,  $HBr$ , and  $HI$ ), fluorocarbon (such as  $CF_4$ ,  $CClF_3$ ,  $CCl_2F_2$ ,  $C_2F_6$ , and  $CBrF_3$ ), halogenated hydrocarbon (such as  $CHClF_2$ ,  $CHBrF_2$ ,  $CHCl_3$ ,  $CH_2Cl_2$ ,  $CH_3CCl_3$ , and  $CCl_4$ ), and  $SF_6$ . Of these examples, fluorocarbons and halogenated hydrocarbons are desirable from the standpoint of easy handling.

10           The following are some examples of the preferred combination of an oxygen-containing gas and a halogen-containing gas.

$O_2 + CCl_2F_2$ ,  $O_2 + CClF_3$ ,  $O_2 + CHClF_2$ ,  $O_2 + CBrF_3$ ,  
 $O_2 + CF_4$ ,  $O_2 + CF_4 + CHCl_3$ ,  $O_2 + CF_4 + CH_2Cl_2$ ,  
15  $O_2 + CF_4 + CCl_4$ ,  $O_2 + CF_4 + CH_3CCl_3$

Any gas which contains both oxygen and halogen may be used alone.

These reactive gases for surface treatment should preferably be diluted with an inert gas  
20 which permits the atmospheric pressure glow discharge to take place easily. Examples of the inert gas include helium, argon, neon, nitrogen, hydrogen, and organic gases. They may be used alone or in combination with one another. Of  
25 these inert gases, helium is desirable.

It is not necessarily essential that these gases be gaseous at normal temperature. They should be fed in a proper way which is selected according to their state (solid, liquid, or gas) at normal temperature and the temperature in the discharge region. Those which are gaseous at normal temperature or at a temperature in the discharge region may be introduced as such into the insulating vessel. Those which are liquid having a comparatively high vapor pressure may be introduced in the form of vapor or after bubbling with an inert gas. The liquid may be applied directly to the surface of vulcanized rubber. Those which are liquid having a comparatively low vapor pressure may be introduced after heating for evaporation or increasing the vapor pressure.

The method for generating the atmospheric pressure plasma is not specifically limited so long as it is capable of generating glow discharge in the neighborhood of atmospheric pressure. Either direct current and alternating current may be used for voltage application, with the latter being industrially easy.

It is possible to generate the AC dis -

charge by using the ordinary inner electrodes. In this case, it is recommended that at least one of the electrodes be coated with an insulator so as to facilitate the stable-  
5 generation of atmospheric pressure plasma. It is also possible to generate the AC discharge by using the outer electrodes if the treating chamber is made of insulator (such as glass). It is also possible to generate the AC discharge  
10 by using coils or waveguides. Incidentally, in the case of DC discharge, it is recommended that both electrodes (for voltage application and grounding) be not coated with an insulator so that a stable DC glow is generated by the direct  
15 flow of electrons from the electrode.

To practice the surface treatment, apparatus as shown in Fig. 41 is usable. This apparatus is made up of a treating chamber 101 and electrodes  
20 104 and 104 arranged therein which generate the region of plasma discharge. An object for surface treatment is placed between the electrodes. The treating chamber 101 is fed with an oxygen-containing gas, a halogen-containing  
25 gas, and a diluent gas through a gas supply pipe

103. Simultaneously with the gas supply, the region of plasma discharge is generated between the electrodes 104 and 104. Incidentally, the electrodes 104 and 104 are coated with an  
5 insulator and spaced opposite to each other at a certain distance, with one of them being connected to an AC voltage 105 and the other being grounded. The surface treatment of an object 102 (vulcanized rubber) takes place in  
10 the space between the electrodes 104 and 104. The exhaust gas is discharged through a discharge pipe 106.

The surface treatment makes the surface of  
15 vulcanized rubber highly adhesive. Therefore, the surface-treated vulcanized rubber can be easily bonded to other materials by heating or pressing or both, which is a well-known bonding method.

20 Other materials to be bonded may be those of plastics, rubber, metal, or ceramics, in any form (such as plate, sheet, fiber, and lump).

The bonding of the surface-treated vulcanized rubber to other materials is  
25 facilitated by the aid of an adhesive, such as



silane coupling agent, aminosilane coupling agent, epoxy adhesive, urethane adhesive, phenol adhesive, acrylic adhesive, and rubber adhesive. A proper adhesive should be selected according to the kind and surface state of the adherents and the method of bonding. No adhesives may be necessary under certain circumstances.

The surface-treating method may be applicable to the production of a composite material of vulcanized rubber, especially to the production of golf balls, anti-vibration rubber, and reclaimed tires.

The present invention may be practised in a simple manner for the surface treatment of vulcanized rubber in a clean environment. After surface treatment, the vulcanized rubber has a much better adhesive surface than that treated with a low-pressure glow plasma. The surface treatment affects only a very thin surface layer, without deteriorating the physical properties of the vulcanized rubber.

#### EXAMPLE

The invention will be described in more

detail with reference to the following examples,  
which are not intended to restrict the scope of  
the invention.

5    Example 1

Using an apparatus as shown in Fig. 10,  
surface treatment was performed on a spherical  
object of polypropylene resin (40 mm in dia-  
meter). The glass insulating vessel 1 (1500 mm  
10 long and 45 mm in inside diameter) inclined  $25^\circ$   
was filled with helium gas containing 1% oxygen  
introduced through the gas inlet 6a. The  
insulating vessel 1 was further supplied with  
helium gas containing 1% oxygen through the gas  
15 inlets 6b located at both ends thereof, so that  
the helium gas leaks slightly from the open ends  
which serve as the entrance and exit of the  
object. An AC voltage (4 kV, 5 kHz) was applied  
across the electrodes 2a and 2b so as to produce  
20 an atmospheric pressure plasma in the vessel 1.  
The spherical object of polypropylene resin 4  
was allowed to roll through the vessel 1 from  
one open end to the other for the surface  
treatment. For comparison, the same procedure  
25 as mentioned above was repeated except that the

vessel 1 was kept horizontal so that the object 4 remained at rest at the center of the vessel 1. Three samples, one rolled during surface treatment, one kept at rest during surface 5 treatment, and one not surface - treated, were tested for surface properties by measuring the contact angle of water at different positions. The results are shown in Table 1.

10 Table 1

		Rolled	Not rolled	Not treated
	Upper part	35°	39°	110°
15	Front part	36°	46°	109°
	Rear part	35°	45°	112°
	Left part	38°	36°	110°
	Right part	40°	38°	110°
20	Lower part	38°	110°	112°
	Average	37°	52.3°	110.5°

It is noted from Table 1 that the object 25 undergoes uniform surface treatment when it is

rolled but the object does not when it is not rolled.

## Example 2

5           The same procedure as in Example 1 was repeated except that helium was introduced through the gas inlets 6a and 6b and the object was replaced by a two-piece solid golf ball (43 mm in diameter) having a covering layer of  
10 thermoplastic ionomer resin in which dimples are formed.

          After surface treatment, the golf ball was coated with a paint, followed by drying. The adhesion of the coating film was evaluated by  
15 cross-hatch test and repeated ball impact test. The results are shown in Table 2. For comparison, the same procedure as mentioned above was repeated except that the surface coating was not performed. The results are also shown in Table  
20 2.

          The cross-hatch test consists of cutting the coating film into small pieces in mutually perpendicular directions, applying a piece of adhesive cellophane tape over the cut coating  
25 film, rapidly pulling off the tape, and counting

the number of pieces removed.

The repeated impact test consists of  
subjecting the finished golf ball to impact  
repeatedly and visually examining the coating  
5 film for peeling from the golf ball.

Table 2

10		Treated ball (Example)	Untreated ball (Comparative Example)
	Cross - hatch test	None peeled out of 10.	9 pieces peeled out of 10.
	Repeated impact test	No peeling after 100 repetitions.	Peeling after 20 repetitions.

15

Example 3

The same procedure as in Example 1 was  
repeated for the surface treatment of a golf  
ball except that the electrode was replaced by  
20 the one shown in Figs. 5 and 6 and a high -  
frequency voltage (13.56 MHz, 100 W) was applied  
across the electrodes. The results were  
identical with those shown in Table 2.

25 Example 4

Using an apparatus shown in Fig. 11, the surface treatment and coating of golf balls were carried out under the same conditions as in Example 2 except that the vessel 1 was swung 6 times per minute, with the maximum slope being 30°. The results were identical with those shown in Table 1.

#### Example 5

Using an apparatus shown in Fig. 12, the surface treatment and coating of golf balls were carried out under the same conditions as in Example 2 except that helium gas was injected into the vessel 1 through the inlet 6 so that the golf ball 4 floated in the vessel 1. The results were identical with those shown in Table 2.

#### Example 6

Using an electrode as shown in Figs. 22 and 23 or an electrode as shown in Figs. 3 and 4, discharging was carried out under the following conditions to compare their discharge starting voltage. The results are shown in Table 3.

Dimensions of the electrodes as shown in Figs.

22 and 23

Insulating vessel: glass, 1500 mm long, 50 mm  
in outside diameter, 45 mm  
in inside diameter

Outer electrode: stainless steel, 240 mm long

Inner electrode: stainless steel, 240 mm long,  
6 mm in diameter

AC frequency: 5 kHz

10

Dimensions of the electrodes as shown in Figs. 3  
and 4

Insulating vessel: the same as above

Two outer electrodes:

stainless steel, 240 mm long,  
with a minimum distance of  
7 mm between electrodes

AC frequency: 5 kHz

20

25

Table 3

Electrode and mode			Discharge start voltage (V)
	Outer electrode	Inner electrode	
Electrode as shown in Figs. 22 and 23.	AC applied	Grounded	1300
	AC applied	Not grounded	1300
	Grounded	AC applied	1100
	Not grounded	AC applied	1100
Electrode as shown in Figs. 3 and 4.			2450

It is noted from Table 3 that it is possible to lower the discharge start voltage if the electrodes are arranged on both outside and inside of the insulating vessel. It is also noted that the discharge start voltage is slightly higher when an AC voltage is applied to the outer electrode than when an AC voltage is applied to the inner electrode. Nevertheless, it is still lower than in the case where the two electrodes are all arranged on the outside. In addition, it is noted that the discharge was stable regardless of grounding.

#### 25 Example 7



Using an apparatus as shown in Fig. 38,  
surface treatment was performed on a two-piece  
solid golf ball (43 mm in diameter) having a  
covering layer of thermoplastic ionomer resin in  
5 which dimples are formed. The glass insulating  
vessel 1 (1500 mm long and 45 mm in inside  
diameter) inclined  $25^\circ$  was filled with helium  
gas introduced through the gas inlet 6a. The  
insulating vessel 1 was further supplied with  
10 helium gas through the gas inlets 6b located at  
both ends thereof, so that the helium gas leaks  
slightly from the open ends which serve as the  
entrance and exit of the golf ball. An AC  
voltage (4 kV, 5kHz) was applied across the  
15 electrodes 2c and 2d so as to produce an  
atmospheric pressure plasma in the vessel 1. A  
golf ball 4 was allowed to roll slowly through  
the vessel 1 from one open end to the other over  
five minutes during which the surface coating  
20 was accomplished.

After surface treatment, the golf ball was  
coated with a clear polyurethane paint, followed  
by drying. The adhesion of the coating film was  
evaluated by cross-hatch test and repeated ball  
25 impact test. The results are shown in Table 4.

For comparison, the same procedure as mentioned above was repeated except that the surface coating was not performed. The results are also shown in Table 4.

5           The cross-hatch test consists of cutting the coating film into small pieces in mutually perpendicular directions, applying a piece of adhesive cellophane tape over the cut coating film, rapidly pulling off the tape, and counting  
10 the number of pieces removed.

          The repeated impact test consists of subjecting the finished golf ball to impact repeatedly and visually examining the coating film for peeling from the golf ball.

15

Table 4

	Treated ball (Example)	Untreated ball (Comparative Example)
20 Cross-hatch test	None peeled out of 10.	9 pieces peeled out of 10.
Repeated impact test	No peeling after 100 repetitions.	Peeling after 20 repetitions.

Example 8

25           The same procedure as in Example 6 was

repeated except that the electrode was replaced by the one shown in Figs. 17 and 18 and a high-frequency voltage (13.56 MHz, 100 W) was applied across the electrodes. The results were-

5 identical with those shown in Table 4.

#### Example 9

Using an apparatus shown in Fig. 39, the surface treatment and coating of golf balls were  
10 carried out under the same conditions as in Example 7. The vessel 1 was swung 6 times per minute, with the maximum slope being  $30^\circ$ . The results were identical with those shown in Table 4.

15

#### Examples 10 - 23 and Comparative Examples 1 - 12

Using an apparatus for atmospheric pressure plasma discharge shown in Fig. 41, surface treatment was performed under the conditions  
20 shown in Table 5 on vulcanized rubber prepared from a rubber compound specified below. After surface treatment, the vulcanized rubber was tested for physical properties (Examples 10 - 23). For comparison, the same experiment as  
25 above was performed on a sample of vulcanized

rubber without surface treatment (Comparative Example 1), a sample of vulcanized rubber treated with a pseudohalogen compound (Comparative Example 2), and samples of vulcanized rubber treated with a low-pressure glow plasma (Comparative Examples 3-12). The results are shown in Table 5.

#### Experiment 1

10		pbw
	Transpolyisoprene	30
	SBR	50
	(#1502, made by Japan Synthetic Rubber)	
	NR	20
15	Sulfur	1
	Zinc oxide	5
	Nocrac NS-6	1
	(made by Ouchi Shinko Kagaku Kogyo)	

A rubber compound specified above was vulcanized, and the vulcanized rubber was made into test pieces measuring 10 × 60 × 3 mm. The test pieces (in Examples 10-18 and Comparative Examples 1-7) underwent surface treatment under the conditions shown in Table 5. The treated surface was coated with a urethane adhesive, and

two test pieces were bonded together, with the coating inside. The bonded test piece underwent T-peel test as shown in Fig. 42 to measure the bond strength. In Fig. 42, the reference numeral 107 represents the vulcanized rubber test piece and the reference numeral 108 represents the urethane adhesive.

#### Experiment 2

Vulcanized rubbers (in Examples 11-18) underwent the surface treatment under the same conditions as in Experiment 1. The treated surface of the test piece was coated with a urethane adhesive and bonded to a piece of polyester nonwoven fabric. The resulting sample underwent 180° peel test as shown in Fig. 43 to measure the bond strength. In Fig. 43, the reference numeral 109 represents the nonwoven fabric.

20

#### Experiment 3

		pbw
	SBR	50
	(#1502, made by Japan Synthetic Rubber)	
25	NR	50

	Carbon black	60
	Sulfur	2
	Zinc oxide	5
	Antioxidant (*1)	1
5	Accelerator (*2)	1

(\*1) N,N' - diphenyl - p - phenylenediamine (DPPD)

(\*2) N - oxydiethylene - 2 - benzothiazole (NOBS)

A rubber compound specified above was vulcanized, and the vulcanized rubber was made into  
 10 test pieces measuring 34 × 75 × 5 mm. The test pieces (in Examples 12 - 18 and Comparative Examples 1, 2, 4 - 7) underwent surface treatment under the conditions shown in Table 5. The treated surface was coated with a phenol  
 15 adhesive, and two test pieces were bonded together, with the coating inside, under pressure at 150°C for 30 minutes. The bonded test piece underwent T-peel test as shown in Fig. 42 to measure the bond strength.

20

#### Experiment 4

		pbw
	NBR	100
	(N2305, made by Japan Synthetic Rubber)	
25	Carbon black	60

	Sulfur	2	
	Zinc oxide	5	
	Antioxidant (*3)	1	
	Accelerator (*4)	1	...
5	Mineral oil	2	

(\*3) N-phenyl-N'-isopropyl-p-

phenylenediamine (NOCRAC 810-NA)

(\*4) Tetramethylthiuram monosulfide (TMTM)

A rubber compound specified above was vulcanized  
 10 at 150°C for 20 minutes, and the vulcanized  
 rubber was made into test pieces measuring 34 ×  
 75 × 5 mm. The test pieces (in Examples 17-23  
 and Comparative Examples 10-14) underwent  
 surface treatment under the conditions shown in  
 15 Table 5. The treated surface was coated with a  
 phenol adhesive, followed by heating in an oven  
 at 150°C for 30 minutes. Using a resin  
 injection machine, glass fiber-filled nylon  
 (50%) was injection molded on the phenolic resin  
 20 adhesive. The resulting sample underwent the  
 180° peel test as shown in Fig. 43 and the area  
 (in terms of %) in which the rubber ruptured was  
 measured.

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Table 5

Ex-ample	Treat-ment	Pres-sure (Torr)	Reactive gas	Diluent gas	Treating time (min.)	Bond strength (kgf/cm)			Rubber rupture Experiment 4
						Experi-ment 1	Experi-ment 2	Experi-ment 3	
10	Atmos-pheric pressure plasma treat-ment	760	O <sub>2</sub> , SF <sub>6</sub>	He	5	2.7	—	—	—
11		760	O <sub>2</sub> , CF <sub>4</sub>	He	5	4.7	2.0	—	—
12		760	O <sub>2</sub> , CClF <sub>3</sub>	He	5	8.6	6.9	12.5	—
13		760	O <sub>2</sub> , CHClF <sub>2</sub>	He	5	8.0	7.2	10.9	—
14		760	O <sub>2</sub> , CCl <sub>2</sub> F <sub>2</sub>	He	5	9.4	7.6	10.6	—
15		760	O <sub>2</sub> , CF <sub>4</sub> , CHCl <sub>3</sub>	He	5	3.6	3.0	9.4	—
16		760	O <sub>2</sub> , CF <sub>4</sub> , CH <sub>2</sub> Cl <sub>2</sub>	He	5	8.7	7.1	6.8	—
17		760	O <sub>2</sub> , CF <sub>4</sub> , CH <sub>3</sub> CCl <sub>3</sub>	He	5	8.1	7.0	7.6	—
18		760	O <sub>2</sub> , CBrF <sub>3</sub>	He	5	7.6	6.1	9.4	—
19		760	O <sub>2</sub> , CF <sub>4</sub>	He	0.5	—	—	—	100
20		760	O <sub>2</sub> , CF <sub>4</sub>	He	1	—	—	—	100
21		760	O <sub>2</sub> , CF <sub>4</sub>	He	2	—	—	—	100
22		760	O <sub>2</sub> , CF <sub>4</sub>	He	5	—	—	—	100
23		760	O <sub>2</sub> , CF <sub>4</sub>	He	10	—	—	—	100



Table 5 (Contd.)

Com- para- tive Ex- ample	Treat- ment	Pres- sure (Torr)	Reactive gas	Diluent gas	Treating time (min.)	Bond strength (kgf/cm)			Rubber rupture (%)
						Experi- ment 1	Experi- ment 2	Experi- ment 3	
1	None	—	—	—	—	0.0	0.0	0.0	—
2	Pseudo — halogen compound	—	—	—	—	7.8	6.4	9.1	—
3	Low — pressure glow plasma treat- ment	1.0	O <sub>2</sub> , SF <sub>6</sub>	—	5	1.3	—	—	—
4		1.0	O <sub>2</sub> , SF <sub>4</sub>	—	5	0.6	—	2.0	—
5		1.0	O <sub>2</sub> , CClF <sub>3</sub>	—	5	1.8	—	1.2	—
6		1.0	O <sub>2</sub> , CHClF <sub>2</sub>	—	5	2.6	—	1.0	—
7		1.0	O <sub>2</sub> , CCl <sub>2</sub> F <sub>2</sub>	—	5	3.8	—	1.4	—
8		1.0	O <sub>2</sub> , CF <sub>4</sub>	—	0.5	—	—	—	50
9		1.0	O <sub>2</sub> , CF <sub>4</sub>	—	1	—	—	—	70
10		1.0	O <sub>2</sub> , CF <sub>4</sub>	—	2	—	—	—	80
11		1.0	O <sub>2</sub> , CF <sub>4</sub>	—	5	—	—	—	10
12		1.0	O <sub>2</sub> , CF <sub>4</sub>	—	10	—	—	—	0

It is noted from Table 5 that in the case of low-pressure plasma treatment (Comparative Examples 8 to 12), the area of rubber rupture increases in proportion to the treating time (in the range of from 0.5 to 2 minutes), whereas it decreases when the treating time exceeds 2 minutes. This leads to poor adhesion. In addition, the area of rubber rupture does not reach 100% even in the case of treatment for 2 minutes which should give the highest value of rubber rupture. By contrast, in the case of atmospheric pressure plasma treatment (Examples 19 to 23), the treatment for 0.5 minute is enough for the rubber rupture to reach 100%. Prolonged treating time does not affect the adhesion properties. The conceivable reason for this is as follows: In the case of low-pressure glow plasma treatment, the rubber is exposed to a plasma atmosphere for a long time under reduced pressure, and consequently the rubber gets hot and gives off a gas which prevents the surface treatment. By contrast, in the case of atmospheric pressure plasma treatment, the rubber is not placed in an atmosphere under reduced pressure, and consequently the

rubber does not give off a gas which prevents  
the stable surface treatment.

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CLAIMS:

1. A method for surface treatment which comprises subjecting an object for surface  
5 treatment to an atmospheric pressure plasma while rolling or floating said object in an insulating vessel fed with a prescribed gas and provided on the outside thereof with electrodes for voltage application and grounding, said  
10 atmospheric pressure plasma occurring upon application of a voltage to said electrodes.

2. A method for surface treatment which comprises subjecting an object for surface treatment to an atmospheric pressure plasma  
15 while rolling or floating said object in an insulating vessel fed with a prescribed gas and provided on the outside and inside thereof with electrodes for voltage application, said atmospheric pressure plasma occurring upon  
20 application of a voltage to said electrodes.

3. The method for surface treatment as defined in Claim 1 or 2, wherein the atmospheric pressure plasma is an atmospheric pressure glow plasma.

25 4. The method for surface treatment as

defined in Claim 1 or 2, wherein the pressure for generating plasma is in the range of about 200 Torr to about 3 atm.

5. An apparatus for surface treatment  
5 which comprises an insulating vessel in which an object for surface treatment is placed, electrodes for voltage application and grounding which are arranged on the outside of the insulating vessel, an electric source to apply a  
10 voltage to said electrodes, a means to supply a prescribed gas to said insulating vessel, and a means to roll or float said object in the insulating vessel, said electrodes generating an atmospheric pressure plasma upon application of  
15 a voltage thereto and said object placed in said insulating vessel being exposed to said atmospheric pressure plasma.

6. An apparatus for surface treatment  
which comprises an insulating vessel in which an  
20 object for surface treatment is placed, two electrodes which are arranged on the outside and inside of the insulating vessel, an electric source to apply a voltage to said electrodes, a means to supply a prescribed gas to said  
25 insulating vessel, and a means to roll or float

said object in the insulating vessel, said electrodes generating an atmospheric pressure plasma upon application of a voltage thereto and said object placed in said insulating vessel  
5 being exposed to said atmospheric pressure plasma.

7. The apparatus for surface treatment as defined in Claim 5 or 6, wherein the atmospheric pressure plasma is an atmospheric pressure glow  
10 plasma.

8. A method for the surface treatment of vulcanized rubber which comprises performing the atmospheric pressure plasma treatment on the surface of vulcanized rubber in the presence an  
15 oxygen-containing gas and halogen-containing gases.

9. A surface-treated article obtainable in accordance with any one of claims 1 to 4.

10. A method, apparatus or article surface-treated  
20 substantially as described herein with reference to the Examples and drawings, but not the Comparative Examples.

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**Patents Act 1977**

**Examiner's report to the Comptroller under  
Section 17 (The Search Report)**

**Application number**

GB 9217744.3

**Relevant Technical fields**

(i) UK Cl (Edition K ) H1D - DGQ, DGP; H1X - X5G;  
C3L - LJE, LJX

(ii) Int Cl (Edition 5 ) H01J; H01T; H05H; C08J

**Search Examiner**

R H LITTLEMORE

**Databases (see over)**

(i) UK Patent Office

(ii)

**Date of Search**

30 NOVEMBER 1992

Documents considered relevant following a search in respect of claims 1-10

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
Y	GB 2164947 A (BRIDGESTONE CORP) Whole document, eg. see Figures 1, 4	1, 2, 5, 6, 8, 9
Y	GB 2059971 A (E A DUKHOVESKOI ETC) See Figures 1 and 3	5, 6, 8, 9
X	EP 0431951 A2 (RES DEV CORP OF JAPAN) Whole document, eg. Figure 1, Claim 1 and column 4 line 15 to column 5 line 14	1-7
X	EP 0267513 A2 (SEMI CONDUCTER ENERGY) Whole document, eg. Figure 4 and column 5 lines 17-51	1-7
Y	EP 0202636 A2 (SHIN-ETSU) eg. See Claim 1	1, 2, 8
X	EP 0178907 A2 (SANKYO DENGYO) Whole document, eg. see Figures 2, 13, 23, 26-28 and page 23 1st paragraph to page 25 1st paragraph	1-9
X	EP 0171239 A1 (SANKYO DENGYO) Whole document, eg. Figures 1, 2 and page 5 line 24 to page 6 line 9	1-9

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Category	Identity of document and relevant passages	Relevant to claim

#### Categories of documents

**X:** Document indicating lack of novelty or of inventive step.

**Y:** Document indicating lack of inventive step if combined with one or more other documents of the same category.

**A:** Document indicating technological background and/or state of the art.

**P:** Document published on or after the declared priority date but before the filing date of the present application.

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**&:** Member of the same patent family, corresponding document.

**Databases:** The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).



**Patents Act 1977**  
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**Section 17 (The Search Report)**

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**Relevant Technical fields**

(i) UK CI (Edition ) Contd. from page 1

(ii) Int CI (Edition )

**Databases (see over)**

(i) UK Patent Office

(ii)

**Search Examiner**

R H LITTLEMORE

**Date of Search**

30 NOVEMBER 1992

**Documents considered relevant following a search in respect of claims**

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
Y	EP 0046945 A1 (TOKYO SHIBAURA) eg. See Figures 1, 2	1, 2, 5, 6
X	US 4724508 (MACY) Whole document, eg. See Figures 1, 6 and 7	1-7

Category	Identity of document and relevant passages	Relevance to claim(s)

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